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Ookubo

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(54) **OBJECT-DISPLACEMENT DETECTOR AND OBJECT-DISPLACEMENT CONTROLLER**

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(52) **U.S. Cl.** **356/614**; 356/620

(58) **Field of Search** 356/614, 615, 356/619, 620, 622, 623

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,601,613 A * 8/1971 Hock 250/205
5,929,983 A * 7/1999 Lu 356/138
6,429,942 B1 * 8/2002 Soares 356/614

FOREIGN PATENT DOCUMENTS

JP	6-294608	10/1994
JP	7-198359	8/1995
JP	7-234119	9/1995
JP	9-166413	6/1997

* cited by examiner

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(57) **ABSTRACT**

An object-displacement detector includes a mirror having a curved surface, the mirror being fixed to an object; a light emitting device for emitting a light; a photo-detector having plural light-receiving regions which are divided in two-dimensional space; and a single optical system having a single optical axis for guiding the emitted light to the mirror and guiding a refracted light from the mirror to the photo-detector for detecting an intensity distribution of the reflected light.

20 Claims, 5 Drawing Sheets

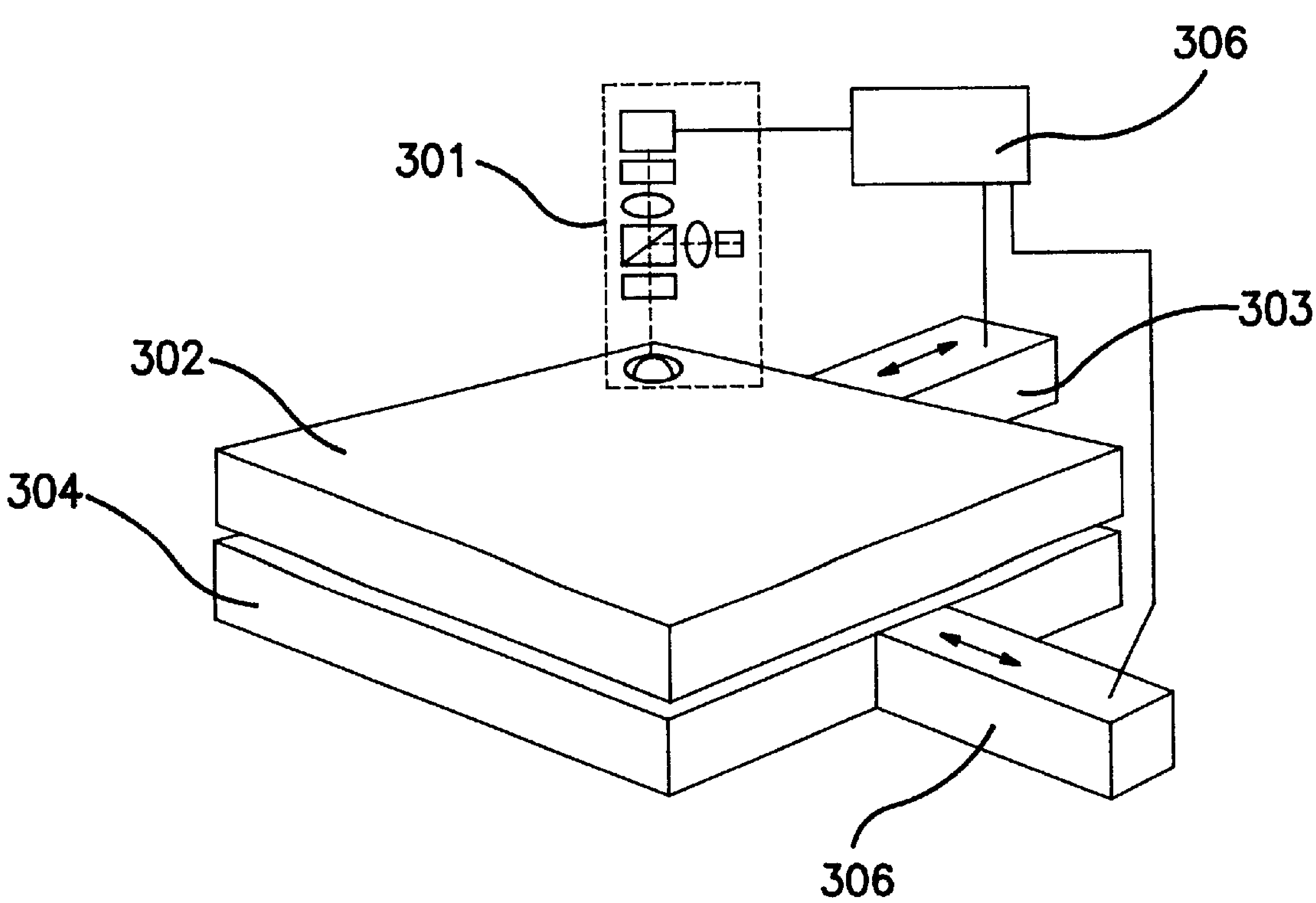


FIG. 1

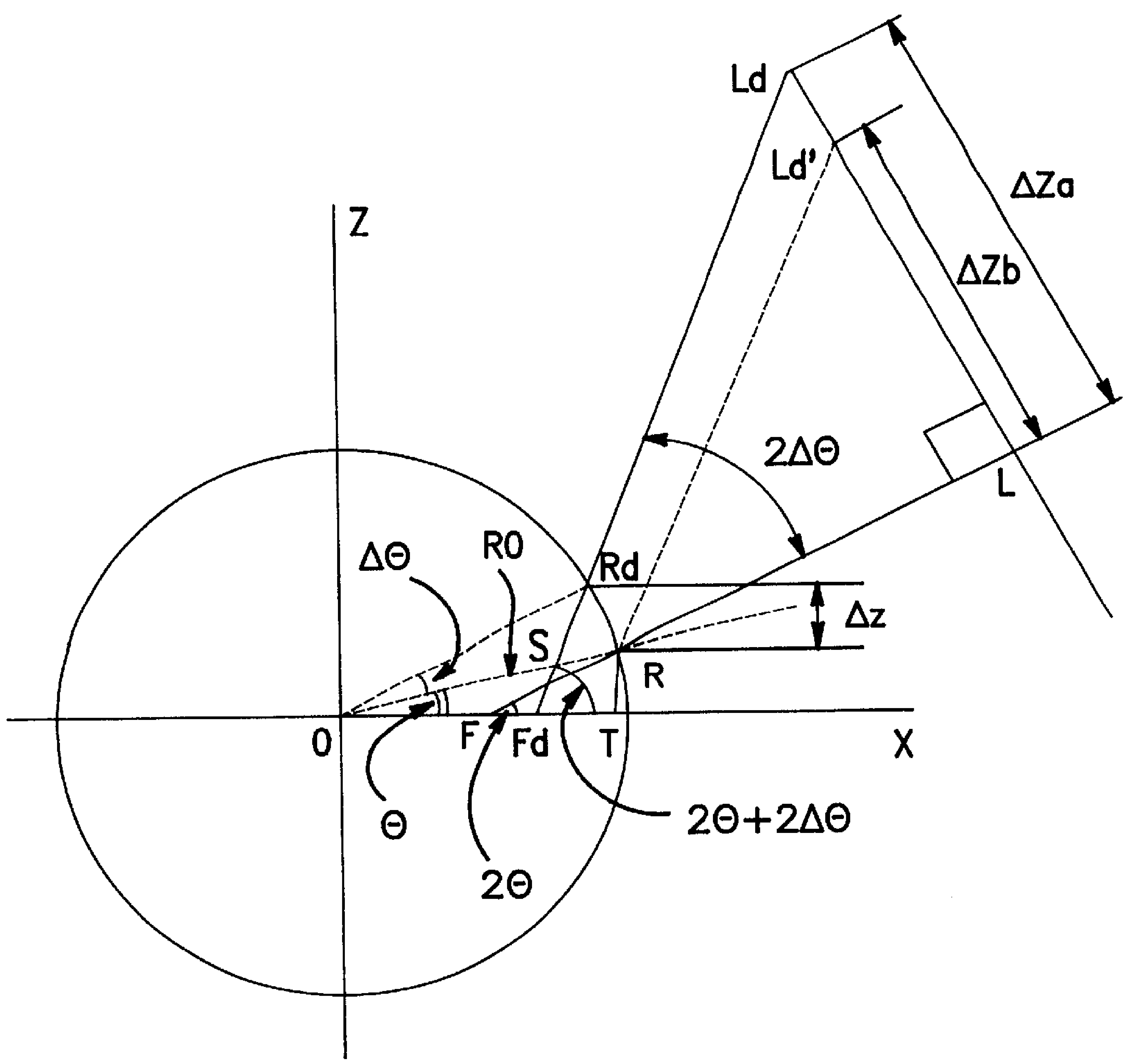


FIG. 2

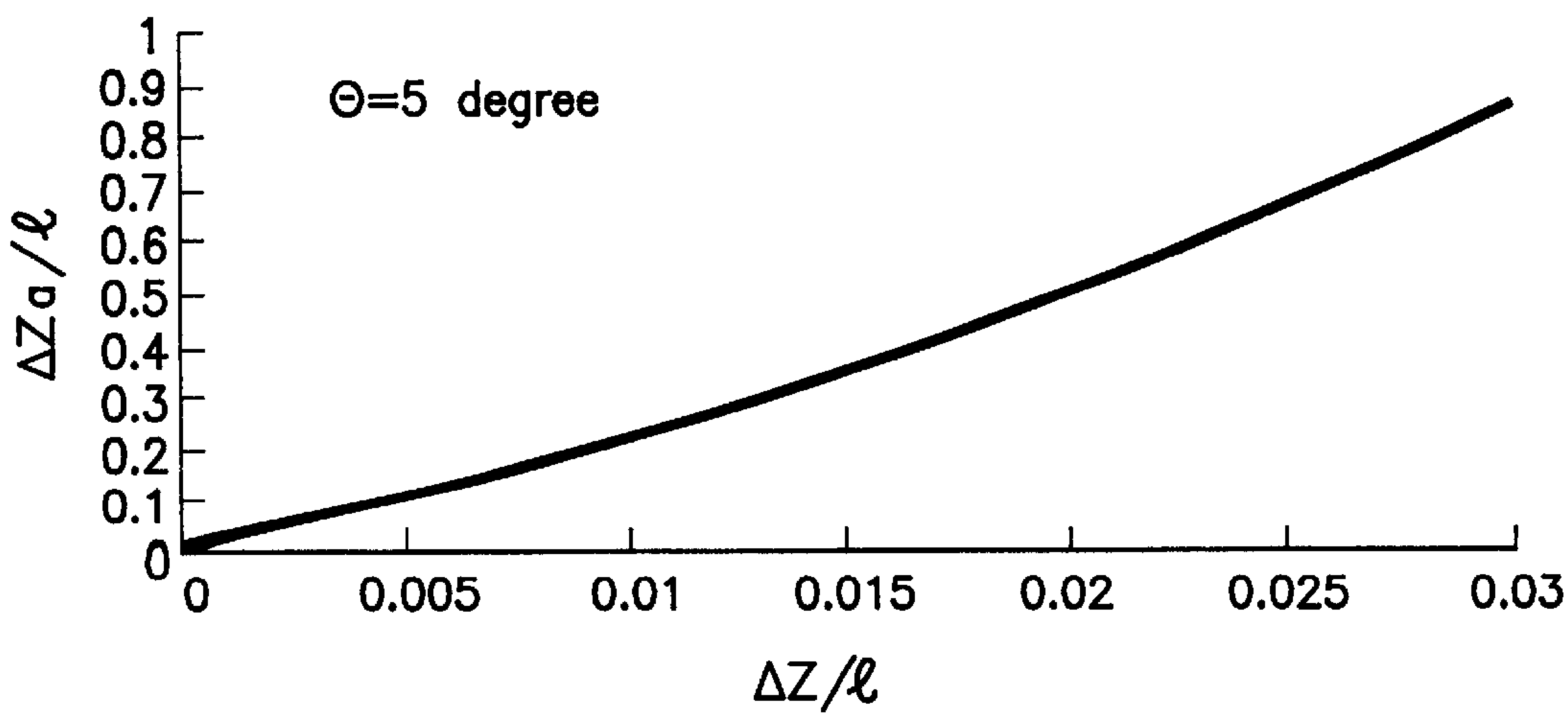

Θ=5 degree
ΔZa/ℓ
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.005
0.01
0.015
0.02
0.025
0.03
ΔZ/ℓ

FIG. 3

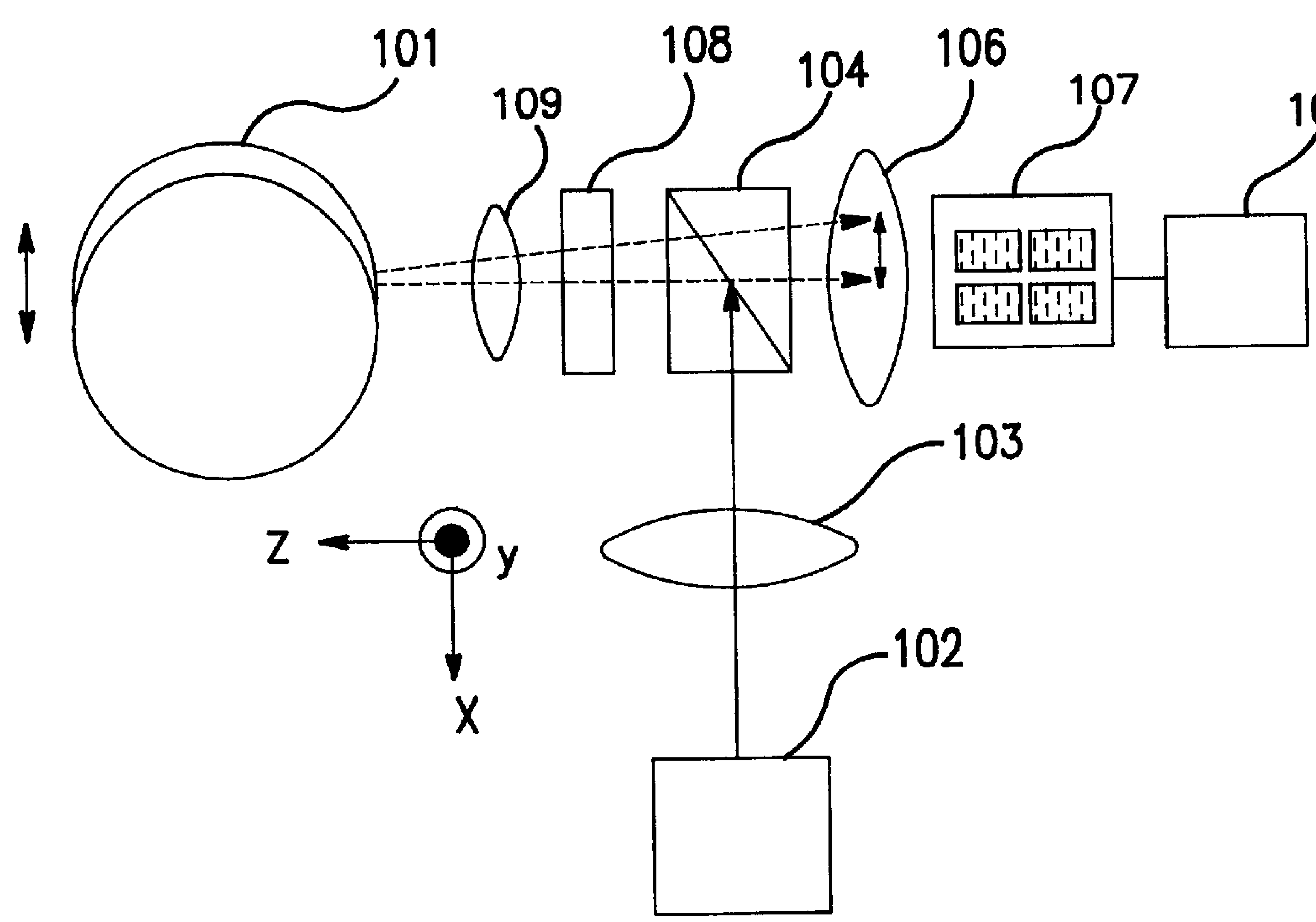


FIG. 4

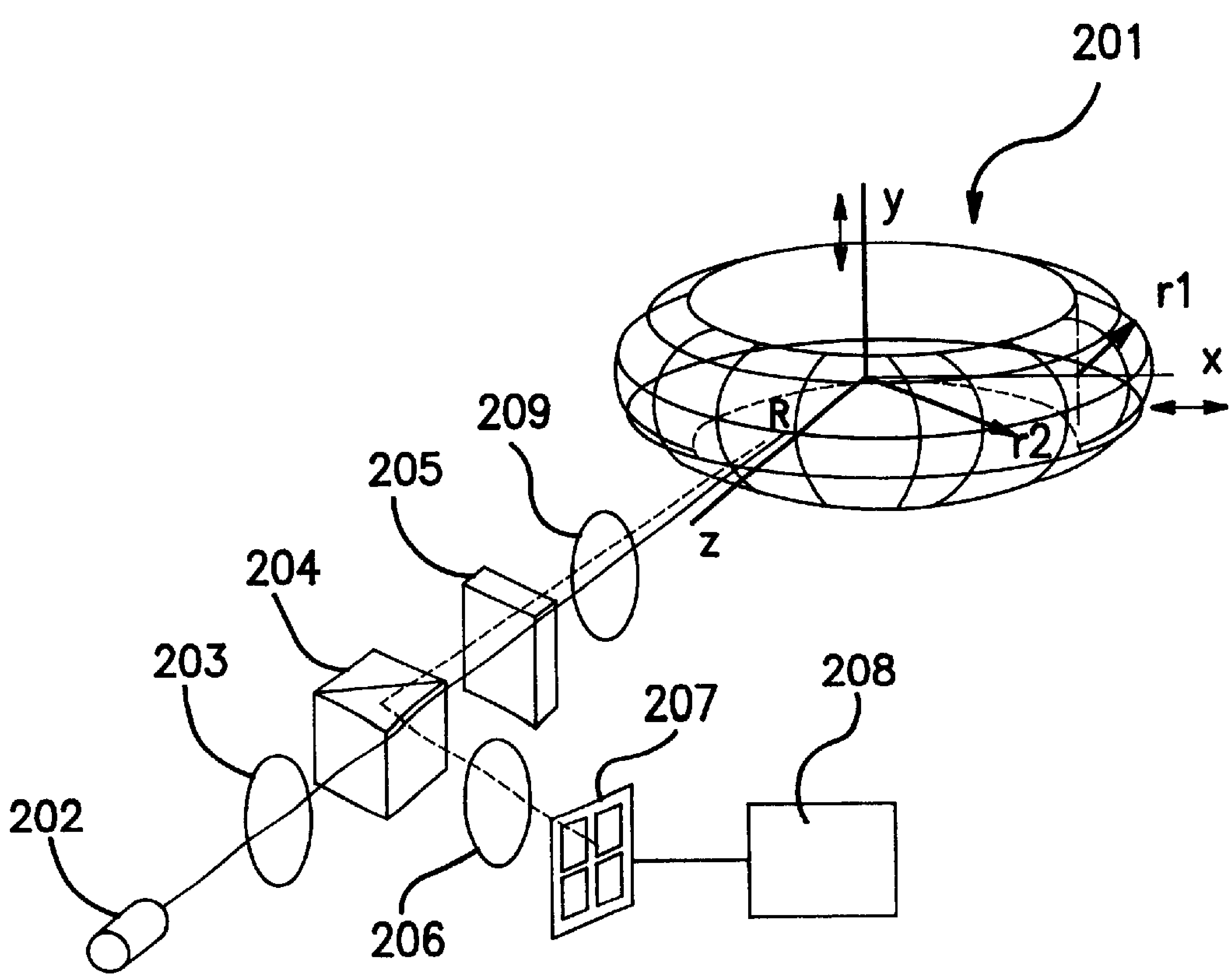
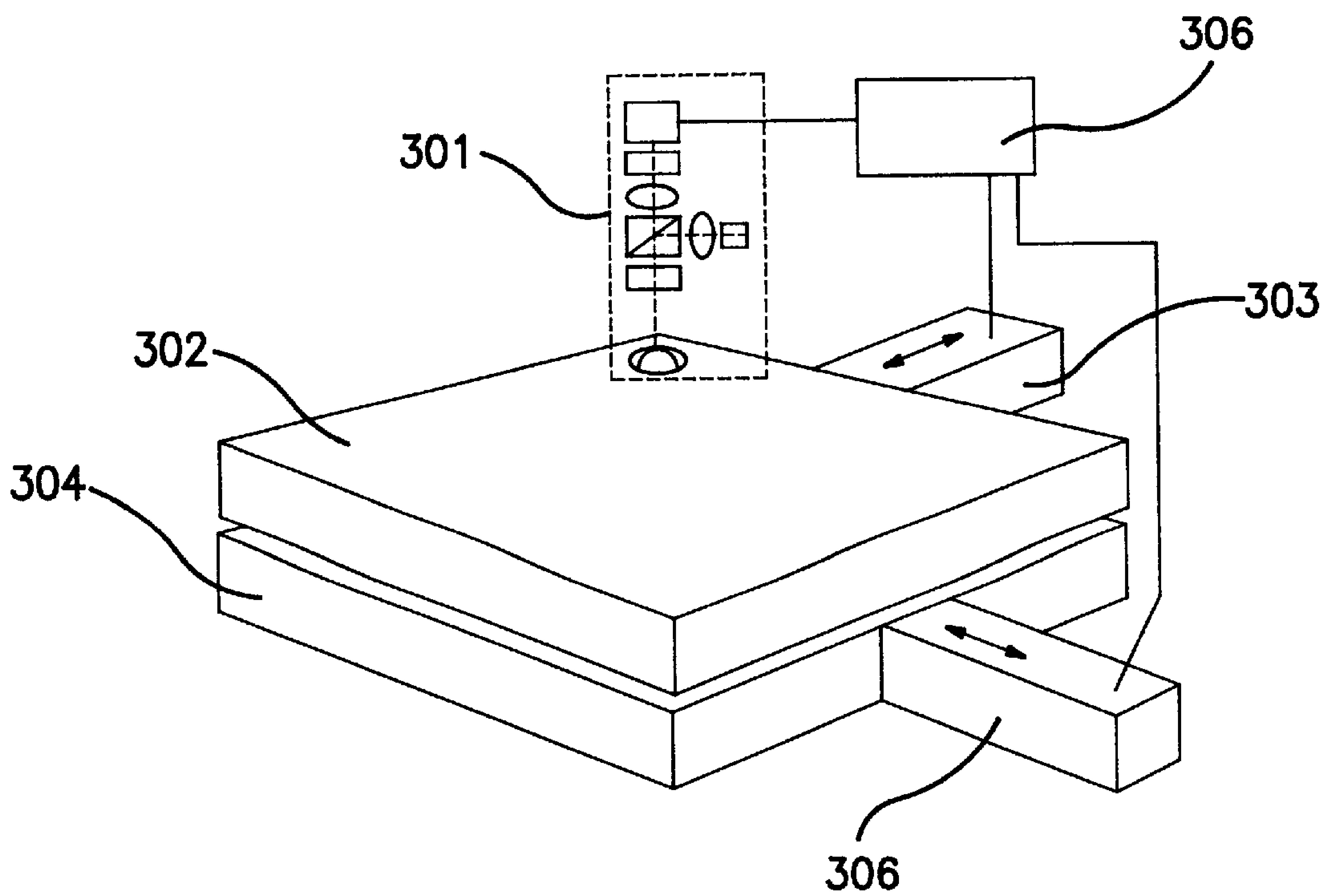


FIG. 5



OBJECT-DISPLACEMENT DETECTOR AND OBJECT-DISPLACEMENT CONTROLLER

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an object-displacement detector and a system for controlling an object-displacement.

2. Description of the Related Art

In order to realize a size reduction of the semiconductor device, it is necessary to realize a highly sensitive detection to an extremely small displacement in the atomic order, for the purpose of controlling the displacement based on the detection result. A piezoelectric device may be used for actuating the object to cause a small displacement thereof. An actual displacement is inter-related in non-linearity with an applied voltage.

The above issue of using the piezoelectric device is caused by the non-linearity between the actual displacement and the applied voltage. As long as the actual displacement is detected based on the applied voltage to the piezoelectric device, it is difficult to detect the displacement without any influence of the non-linearity,

Further, it has been known to utilize an optical interference between the object and a reference mirror. This method has a disadvantage in the non-linearity between the detected displacement and the actual displacement, and also another disadvantage in the correspondence of a single detected displacement to plural actual displacements.

Furthermore, it has also been known to utilize a variation in optical quantity upon shielding the light for detecting the displacement. This method has still another disadvantage in difficulty to detect a slight displacement.

In the above circumstances, the development of a novel object-displacement detector free from the above problems is desirable.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a novel object-displacement detector free from the above problems.

It is a further object of the present invention to provide a novel object-displacement detector having a simple structure with a single optical axis.

It is a still further object of the present invention to provide a novel object-displacement control system free from the above problems.

It is yet a further object of the present invention to provide a novel object-displacement control system utilizing a novel object-displacement detector having a simple structure with a single optical axis.

The present invention provides an object-displacement detector comprising: a mirror having a curved surface, and said mirror being fixed to an object; a light emitting device for emitting a light; a photo-detector having plural light-receiving regions which are divided in two-dimensional space; and a single optical system having a single optical axis for guiding said emitted light to said mirror and guiding a refracted light from said mirror to said photo-detector for detecting an intensity distribution of said reflected light.

The above and other objects, features and advantages of the present invention will be apparent from the following descriptions.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments according to the present invention will be described in detail with reference to the accompanying drawings.

FIG. **1** is a diagram of a principle of a position-detecting method used by an object-displacement detector of the present invention.

FIG. **2** is a graph of an example of the inter-relationship between ΔZ and ΔZa.

FIG. **3** is a block diagram of a two-dimensional object-displacement detector in accordance with the present invention.

FIG. **4** is another object-displacement detector in accordance with the present invention.

FIG. **5** is a schematic view of a displacement control system including the object-displacement system in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A primary aspect of the present invention is an object-displacement detector comprising: a mirror having a curved surface, and said mirror being fixed to an object; a light emitting device for emitting a light; a photo-detector having plural light-receiving regions which are divided in two-dimensional space; and a single optical system having a single optical axis for guiding said emitted light to said mirror and guiding a refracted light from said mirror to said photo-detector for detecting an intensity distribution of said reflected light.

In accordance with the present invention, in place of the applied voltage to the piezoelectric device, the optical displacement-detector is used for optically detecting the displacement of the object by use of the photo-detector. Since the displacement detection is made without depending on the applied voltage to the piezoelectric device, the novel displacement detector is free from the above problems and disadvantages.

Further, the novel displacement detector does not utilize an optical interference between the object and a reference mirror, for which reason the novel displacement detector is free from the non-linearity between the detected displacement and the actual displacement, and also from the correspondence of a single detected displacement to plural actual displacements.

Furthermore, the novel displacement detector does not utilize a variation in optical quantity upon shielding the light for detecting the displacement, for which reason the novel displacement detector may detect a slight displacement.

The novel displacement detector optically amplifying the actual displacement of the object with the simple structure. This allows various applications of the novel displacement detector.

A preferred embodiment according to the present invention will be described in detail with reference to the drawings. FIG. **1** is a diagram of a principle of a position-detecting method used by an object-displacement detector of the present invention.

A spherical mirror attached on an object has an origin “O” and a circumferential point “R”. A flux of incident light is incident onto the circumferential point “R”. The flux is in a Z-X plane. The Z-axis is parallel to a direction of the flux. A relative displacement between the flux and the spherical mirror appears on the Z-axis.

If the movable object is not displaced, then the incident light is reflected by the circumferential point "R". The reflected light passes through a lens surface point "L" which is vertical to a flux of the reflected light At this time, the reflected light has an incident angle θ, to a cylindrical face, wherein the incident angle θ corresponds to an included angle between a line segment R**0** and the X-axis.

If in proportion to a Z-directional displacement of a movable object, the flux is displaced by ΔZ in the Z-direction, then the light is incident into another circumferential point "Rd" with an incident angle of θ+Δθ.

The reflected light passes through another lens surface point "Ld" wherein a displacement of the flux on the lens surface corresponds to a length "ΔZa" of the line segment "L-Ld". Namely, if the object is displaced by ΔZ, then the displacement "ΔZa" of the flux on the lens surface is detected.

A perpendicular line segment, which includes the circumferential point "R", has a cross-point "T" on the X-axis, wherein the perpendicular line segment is perpendicular to the X-axis. An extending line segment from a line segment including the points "R" and "L" has another cross-point "F" on the X-axis. A length f(θ) of a line segment "OF" is given by the following equation (1).

$$f(\theta)=(r/2)\sec\theta \quad (1)$$

where "r" is the radius of the spherical mirror.

A length of the line segment RL is set **1**. The length of the line segment FR is identical with the length f(θ) of the line segment "OF". A displacement "ΔZa" of the flux on the lens in response to the displacement by "ΔZ" of the incident light flux on the mirror surface is given by the following equation (2).

$$\Delta Za=(1+f(\theta)-\Delta\mathbf{1})\tan 2\Delta\theta \quad (2)$$

wherein Δ**1** is the length of the line segment FS.

The above equation (2) is represented by substituting θ and Δθ.

$$\Delta Za=1\ \tan 2\Delta\theta+2r\cos(\theta+3\Delta\theta/2)\sec(2\Delta\theta)\sin\Delta\theta/2 \quad (3)$$

The displacement ΔZ of the flux by the displacement of the movable object may be represented with θ and A θ as follows.

$$\Delta Z=r\{\sin(\theta+\alpha\theta)-\sin\theta\} \quad (4)$$

An inter-relationship between ΔZ and ΔZa may be founded with parameters θ and Δθ.

FIG. **2** is a graph of an example of the inter-relationship between ΔZ and ΔZa. The inter-relationship between ΔZ and ΔZa has a linearity, provided that ΔZ /1 is not more than about 0.02, and r/1≈0.1. If θ, which indicates the incident position, is decreased, then ΔZa is about ten times of the displacement ΔZ from 0 to about 0.2r, wherein the ΔZ is subjected to the linear amplification.

FIG. **3** is a block diagram of a two-dimensional object-displacement detector in accordance with the present invention. The detector may include a spherical mirror **101** attached on a surface of a movable object, an optical system having a single optical axis, a light emitting device **102**, a four-divided photo-detector **107** and a differential photo-current detector **108** which is electrically connected to the four-divided photo-detector **107**.

The optical system may further include a collimator lens **103**, a polarization beam splitter **104**, a quarter wavelength plate **105**, a lens **109**, and a lens **106**. The lens **109**, the quarter wavelength plate **105**, the polarization beam splitter **104**, the lens **106**, and the four-divided photo-detector **107** are aligned on a single optical axis. The collimator lens **103** is positioned between the light emitting device **102** and the polarization beam splitter **104**. The lens **106** is positioned between the polarization beam splitter **104** and the four-divided photo-detector **107**. The quarter wavelength plate **105** is positioned between the polarization beam splitter **104** and the lens **109**. The lens **109** is positioned between the quarter wavelength plate **105** and the spherical mirror **101**.

A light is emitted from the light emitting device **102**. The light is collimated by the collimator lens **103**. The collimated light is then transmitted to the polarization beam splitter **104**, and a part of the light is then transmitted toward the mirror **101**. The light is then made by the quarter wavelength plate **105** into a circular polarization light. The circular polarization light is then transmitted through the lens **109** and incident to a surface of the mirror **101** with a spot having a diameter of about **30** micrometers. The spherical mirror **101** has a curvature corresponding a diameter of about 1 millimeter.

The light is reflected by the mirror **101** with inversion of sense of the circular polarization. The reflected light is then transmitted through the lens **109** to the quarter wavelength plate **105**, whereby the circular polarization light is made into the linear polarization light. The light is further transmitted through the polarization beam splitter **104** to the four-divided photo-detector **107**. The light is received by the four-divided photo-detector **107**. The four-divided photo-detector **107** has four-divided light receiving regions for separately receiving parts of the light beam spot. The four-divided photo-detector **107** outputs four separate photo-currents which accord to the four-divided light receiving regions. The four separate photo-currents are then sent to the differential photo-current detector **108** which provide positional signals which indicate the position of the object in X-Y coordinates system. If the four separate photo-currents have the same intensity, then the positional signal from the differential photo-current detector **108** is zero voltage.

If the movable object has no displacement in the X-Y coordinate system, the positional signal from the differential photo-current detector **108** is zero voltage.

If the movable object has a displacement in the X-Y coordinate system, then the position of the light beam spot on the four-divided photo-detector **107** is displaced from the center position of the four-divided photo-detector **107**, whereby differential values of the output signals from the four-divided photo-detector **107** are different from those obtained when the movable object has no displacement. The differential photo-current detector **108** provides the signal which indicates the two-dimensional displacement of the object on the X-Y coordinate system.

The aperture number of the lens **109** may be optional depending on the size of the spherical mirror **101** and the optical elements between the mirror **101** and the lens **106** If unnecessary, it is possible that the lens **109** is not provided.

If a length of the optical transmission route from the light emitting device **102** is long, then it is preferable to provide the collimator lens **103**. If, however, the length of the optical transmission route is short, then it is possible that the collimator lens **103** is not provided,

The four-divided photo-detector **107** may optionally be provided at the same position as the lens **106**, without providing the lens **106**.

In the above preferred embodiment, the mirror is the spherical mirror which has the same curvatures in both X and Y directions, whereby the detector has the uniform sensitivity depending on direction.

It is, however, possible to replace the spherical mirror **101** with a toroidal-shaped mirror which has different curvatures in X and Y directions, whereby the detector has different sensitivities in X and Y directions. FIG. **4** is another object-displacement detector in accordance with the present invention. The other object-displacement detector is different from the above detector but only in the mirror. The other object-displacement detector has a toroidal-shaped mirror **201** which has different curvatures in X and Y directions, whereby the detector has different sensitivities in X and Y directions. The remaining elements of the other object-displacement detector arc the same as described above. Operations of the other object-displacement detector of FIG. **4** is the same as those of the detector of FIG. **3**.

The toroidal-shaped mirror **201** may have a first radius **r1** of about 0.5 millimeters and a second radius **r2** of about 10 millimeters. The sensitivity in Y-direction is larger by ten times than the sensitivity in X-direction.

The above two object-displacement detectors may be applied to the following displacement control system. FIG. **5** is a schematic view of a displacement control system including the object-displacement system in accordance with the present invention.

The displacement control system may include a pair of top and bottom stages **302** and **304**, a first piezoelectric device **303** fixed to the top stage **302**, a second piezoelectric device **305** fixed to the top stage **304**, an object-displacement detector **301** for detecting a displacement of an object mounted on the top stage **302**, and a controller **306** being connected to the object-displacement detector **301** and the first and second piezoelectric devices **303** and **305**.

The object-displacement detector **301** may have the same structure as either one of the above-described object-displacement detectors of FIGS. **3** and **4**.

The second piezoelectric device **305** is driven to actuate the bottom stage **304** in X-direction. The first piezoelectric device **303** is driven to actuate the top stage **302** in Y-direction. Since the top stage **302** is mounted on the bottom stage **304**, the top stage **302** is movable in two-dimensional directions in the X-Y coordinate system.

The mirror is attached on the surface of the object mounted on the top stage **302**. The object-displacement detector **301** detects the object-displacement in the two-dimensional direction and transmits the detected signal to the controller **306**, wherein the detected signal indicates the object-displacement in the two-dimensional direction. The controller **306** compares the detected signal with a reference signal which indicates a reference position of the object, for obtaining a difference in two-dimensional position of the object-position from the reference position. The controller **306** amplifies the difference. The amplified difference is negatively fed back to the first and second piezoelectric devices **303**.

The above-described present invention is applied to a stopper to be used in the semiconductor manufacturing processes.

The above novel detector is advantageous in simple structure and in using a single optical axis system.

Although the invention has been described above in connection with several preferred embodiments therefor, it will be appreciated that those embodiments have been provided solely for illustrating the invention, and not in a limiting sense. Numerous modifications and substitutions of equivalent materials and techniques will be readily apparent to those skilled in the art after reading the present application, and all such modifications and substitutions are expressly understood to fall within the true scope and spirit of the appended claims.

What is claimed is:

1. An object-displacement detector comprising:

a mirror having a curved surface, and said mirror being fixed to an object;

a light emitting device for emitting a light;

a photo-detector having plural light-receiving regions which are divided in two-dimensional space; and

a single optical system having a single optical axis for guiding said emitted light to said mirror and guiding a refracted light from said mirror to said photo-detector for detecting an intensity distribution of said reflected light.

2. The object-displacement detector as claimed in claim **1**, further comprising a converter being connected to said photo-detector for converting said detected intensity distribution of said reflected light to a displacement signal.

3. The object-displacement detector as claimed in claim **1**, wherein said mirror comprises a spherical mirror.

4. The object-displacement detector as claimed in claim **1**, wherein said mirror has first and second curvatures in first and second directions perpendicular to each other, and said second curvature being different from said first curvature.

5. The object-displacement detector as claimed in claim **4**, wherein said mirror comprises a toroidal-shape mirror.

6. The object-displacement detector as claimed in claim **1**, wherein said mirror has a single curvature in a single direction for detecting a displacement of said object in said single direction.

7. The object-displacement detector as claimed in claim **1**, wherein said optical system includes a polarization beam splitter, and a quarter wavelength plate.

8. The object-displacement detector as claimed in claim **7**, wherein said optical system further includes a first lens provided between said mirror and said quarter wavelength plate.

9. The object-displacement detector as claimed in claim **8**, wherein said optical system further includes a second lens provided between said polarization beam splitter and said photo-detector,

said first lens, said quarter wavelength plate, said beam splitter, said second lens, and said photo-detector being aligned in a single, straight line optical axis.

10. The object-displacement detector as claimed in claim **7**, wherein said optical system further includes a third lens provided between said light emitting device and said polarization beam splitter, and said third lens comprises a collimator lens.

11. A system for controlling a displacement of an object, said system comprising:

an actuator for moving a mount which mounts said object;

a controller being connected to said actuator for sending a control signal to said actuator, so that said actuator moves said mount under said control signal; and

an object-displacement detector for detecting a displacement of said object mounted on said mount,

wherein said object-displacement detector further comprises

a mirror having a curved surface, and said mirror being fixed to an object;

a light emitting device for emitting a light;

a single photo-detector having plural light-receiving regions which are divided in two-dimensional space; and a single optical system having a single optical axis for guiding said emitted light to said mirror and guiding a refracted light from said mirror to said single photo-detector for detecting an intensity distribution of said reflected light.

12. The system as claimed in claim **11**, further comprising a converter being connected to said photo-detector for converting said detected intensity distribution of said reflected light to a displacement signal.

13. The system as claimed in claim **11**, wherein said mirror comprises a spherical mirror.

14. The system as claimed in claim **11**, wherein said mirror has first and second curvatures in first and second directions perpendicular to each other, and said second curvature being different from said first curvature.

15. The system as claimed in claim **14**, wherein said mirror comprises a toroidal-shape mirror.

16. The system as claimed in claim **11**, wherein said mirror has a single curvature in a single direction for detecting a displacement of said object in said single direction.

17. The system as claimed in claim **11**, wherein said optical system includes a polarization beam splitter, and a quarter wavelength plate.

18. The system as claimed in claim **17**, wherein said optical system further includes a first lens provided between said mirror and said quarter wavelength plate.

19. The system as claimed in claim **17**, wherein said optical system further includes a second lens provided between said polarization beam splitter and said photo-detector.

20. The system as claimed in claim **17**, wherein said optical system further includes a third lens provided between said light emitting device and said polarization beam splitter, and said third lens comprises a collimator lens.

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